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Comparison of dual isolated converters with flyback converters for bidirectional energy transfer

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ABSTRACT

This article demonstrates a proposed technique for improving single-stage rectifiers' power factor (PF) and controlling the load voltage in response to grid voltage and load changes. To alleviate the above problem, this article offers a novel bi-directional continuous switching pulse width modulation (CSPWM) and sinusoidal pulse width modulation (SPWM) based converter that can improve PF and reduce harmonics. This converter is evaluated based on two cases, Case I: CSPWM-based rectification and SPWM-based inversion scheme, and Case II: Rectification and inversion, both operations using the SPWM scheme. The proposed control scheme uses two Bi-directional IGBTs and two diodes, which are bridgeless, do not need a transformer, and are free from the output current sensor. The suggested scheme is simulated using MATLAB/Simulink and implemented on DSPic33FJ64mc802 platforms to validate the effectiveness of the proposed approach using two cases for a 1 KW system. The suggested control scheme provides improved PF, good voltage regulation, and depreciation in harmonics and total harmonic distortions (THD) compared to existing systems that enhance converter performance.

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1. INTRODUCTION

Most AC-DC power conversion applications need stabilized direct current (DC) output voltage with better steady state and transient response. The capacitor filter-based rectifier is simple and cheap; however, it degrades the supply voltage quality, compromising the response of other loads linked to it and producing other issues [1], [2]. Power electronics researchers have been inventing new ways for a superior efficacy interface since the mid-1980s to achieve these mandated standards. PF correction (PFC) circuits are the collective name for these new circuits. Power converters are essential for microgrids, smart grids, electric vehicles, industrial machinery, and commercial products [3]-[5].

A single-switch rectifier circuit is the most straightforward scheme for hysteresis current control where the band is increased [6], [7]. The two switches rectified have significantly improved over the traditional single ones [8], [9]. The typical AC-DC converter (rectifiers) use diodes but suffer from poor power quality, more considerable voltage distortions, inferior PF at primary input, low effectiveness, and bulky nature of alternating current (AC) and DC filters [10]. The Vienna rectifier generates a DC voltage across the two switches linked to the primary side of the transformer, which is represented by [11]-[13]. Even though it only has three switches, the Vienna rectifier is more stressed than a six-switch converter. On the other hand, the Vienna rectifier is concerned with poor current regulation during overload, start-up over current, and the inability to operate bi-directionally.

Preview study [14], researchers present a single-phase multilevel flying capacitor active rectifier with hysteresis-based control. Controlling the input current allows for PF and output voltage management. When the frequency ratio changes, PLL is employed to determine the phase information of the input voltage that causes transients. The researchers in [15] propose an intelligent charger for electric vehicles that uses three-wire distribution feeders. They used six active switches to accomplish bi-directional flow, which boosts hardware, cost, switching losses, and complexity. An efficient vehicle-to-grid (V2G) and grid-to-vehicle (G2V) converter systems for EV applications were proposed in [16]. A simple bi-directional power line communication (PLC) method is proposed by switching ripples in a DC-DC converter [17]. Current ripples in the input side of converters are used as signal carriers whose frequency is modified as a function of transmission data. G2V and V2G applications are the primary goals of this bidirectional on-board single-phase electric vehicle charger.

A high gain boost converter and buck converter are the essential components of the bidirectional charger arrangement. The battery state of charge (SoC) is used to charge and discharge the battery [18]. The converter's topology comprises three MOSFET switches, four capacitors, and two inductors. Furthermore, lowering switching losses improves the converter's efficiency in various applications such as electric vehicles, energy storage systems, distribution generation, and microgrids [19]. The CLLC bidirectional resonant converter (CCLC-BRC) maintains the advantages of the LLC resonant converter, such as high performance and power density. It provides a symmetrical bidirectional voltage gain, making it suited for scenarios with bi-directional power flows. A small-signal model for the CLLC-BRC was developed using the augmented description function method [20]. Dual active bridge (DAB) DC-DC converters provide a unified phase shift control technique for better transient current response [21]. A bidirectional charger is employed to transfer energy from the battery to the AC side for grid assistance. Furthermore, an active bridge permits synchronous rectification on the secondary side to minimize conduction losses [22].

Partial differential equations design networks with many components (PDEs). The components count in the network decides the convergence of a sequence. The sequence meets a range boundary as N approaches infinity, the solution of a particular PDE [23]. The efficiency and operation stability of an isolated bidirectional boost full bridge DC-DC converter using active start-up assisting circuit and an active voltage clamping snubber [24]. A bidirectional three-phase AC/DC DAB converter is utilized for the high-frequency connection based on a novel modulation scheme that is realized using sinusoidal line currents [25]-[27] and zero voltage switching (ZVS) by exact regulation of phase shift and duty cycle under bidirectional operation [28]. The main drawbacks of a three-phase conventional bridge inverter are inferior electromagnetic compatibility, lesser dv/dt stresses, and a reduced rating than multilevel inverters [29], [30].

Considering all the above literature, it has been seen that there is scope to optimize the system. The critical contributions of the proposed system are:
- It achieved the rectifier PF that was nearer to unity;
- It successfully achieved the bi-directional power flow;
- It stabilized the DC output voltage of the rectifier in case of changes in the grid;
- It successfully reduced total harmonic distortions as much as possible (THDs); and
- It can minimize total harmonic distortions by achieving bi-directional power flow (THDs).

This research article provides a comparative analysis of two examples (Case I - rectification with CSPWM and inversion with SPWM scheme, Case II - rectification and inversion both with SPWM scheme). The converter utilized has no bridges, transformers, or output DC sensors. All of the above methods are executed digitally to take advantage of the benefits of digital implementation. The detailed simulation is performed using MATLAB/Simulink, and an experimental setup for a 1KW system is created to validate it.

The outstanding article is arranged as follows: i) section 2 elaborates on the block diagram and discusses the suggested methodology in detail; ii) section 3 provides details about the design and modeling of the proposed scheme; iii) section 4 emphasizes the simulation results and deliberations; finally, iv) section 5 offers the conclusion of the work.

2. PROPOSED METHOD

2.1. Case I: Rectification using CSPWM and inversion using SPWM scheme

Figure 1 illustrates the schematic of the suggested scheme for Case I, where the rectification operation uses continuous switching PWM and the inversion operation uses a sinusoidal PWM scheme. In the CSPWM scheme, only lower switches S2 and S4 of the bi-directional converter are operated. Upper switches S1 and S3 act as diodes to pass current to complete the circuit path. The CSPWM scheme gives higher PF and regulates DC link voltage in significantly less time. This scheme uses DC link voltage as an input called feedback DC link voltage. Based on it, all the rectification parameters are achieved. S4 is used in the sinusoidal PWM scheme. In the sinusoidal PWM scheme, to achieve a positive half cycle (PHC) of inverted AC signal, the S1 and S4 switches are ON, and for the negative half cycle (NHC), the S2 and S3 are activated. The variation in duty cycle to achieve sinusoidal output, value of Kfactor, and array value of look-up tables are used. This scheme uses AC line voltage as VAC feedback input; sinusoidal AC line voltage is achieved.

2.2. Case II: Rectification and inversion of both operations using the SPWM scheme

Figure 2 illustrates the schematic of the suggested scheme for Case II, where rectification and inversion operations are performed using the SPWM scheme. Only lower switches S2 and S4 of the bi-directional converter are used for rectification. Upper switches S1 and S3 act as diodes to pass current to complete the circuit path. In the SPWM scheme, the duty cycle increases slowly. Hence, the current flowing at the input side is less or is in the duty cycle proportion. Due to this, the PF of the front-end converter is less, and the time required to maintain the DC link voltage is somewhat more. This scheme uses DC link voltage as an input called feedback DC link voltage, and based on it, all the rectification parameters are achieved. In an inversion operation using the SPWM scheme, all four switches, S1, S2, S3, and S4, are used. To achieve a PHC of inverted AC signal, S1, and S4 switches are ON, and for a NHC, S2, and S3 are activated. The variation in duty cycle to achieve sinusoidal output, value of Kfactor, and array value of look-up tables are used. This scheme uses AC line voltage as input, called VAC feedback, based on its sinusoidal AC line voltage achieved. This scheme is implemented in the same way as implemented in Case I inversion.

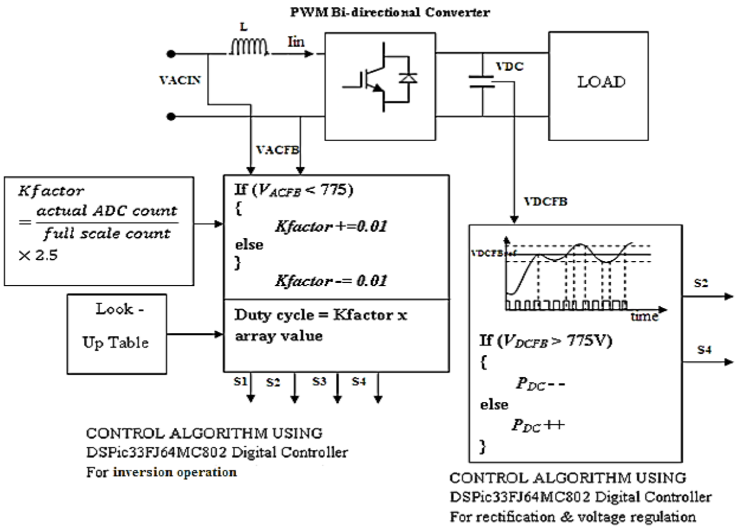


Figure 1. Block schematic of the suggested scheme in Case I

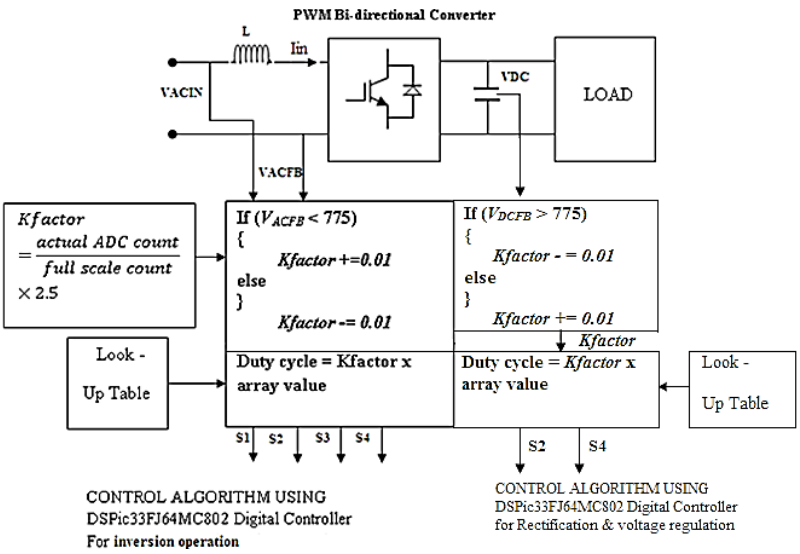


Figure 2. Block schematic of the suggested scheme in Case II

3. DESIGN AND MODELING OF THE SYSTEM

3.1. Modeling of switch and driver

The IGBT switch (IRF4G50WD) is used as a switch because of its higher switching frequency and larger current conduction capacity. The IGBT can operate at a larger switching frequency and handle more power. The IGBT switches are used for the active conversion of voltage sources. Out of two available drivers of IGBT (IR210-International Rectifier and VLA 503 hybrid driver), VLA 503 drive is used for driving the switch because of its distinctive features, such as:

- Better electrical isolation between input and output with the help of an optocoupler.
- No need for bootstrap operation.
- Turning OFF the switch due to +15 V and -9 V provision.

3.2. Modeling of controller

The DSPic33FJ64mc802 is employed to model the proposed controller, which is application-specific integrated circuits that provide various onboard and inbuilt functions as described in Table 1. The design of the controller is based on the fact that the steady-state error should be zero, and at zero, the cross-over period gain should be high. The DSPic33FJ64mc802 has 10-bit ADC, 64 Kbytes Linear data memory, 16 Kbytes RAM, 64 Kbytes flash program memory. It requires 3.3 operating voltage and has 28 IC pins.

Table 1. Specifications of DSPic33FJ64mc802

Parameter	Specification
ADC	10 bit
Linear data memory	64 kB
RAM	16 kB
Flash program memory	64 kB
Operating voltage	3.3 V
Digital signal controller	16 bit
IC pins	28

3.3. Input inductor design

The proposed design considers the inductor ripple current 40% of the output current, as given in (1). The ripple current of inductor typically lies between 20% to 40% of the load current. The inductor value is obtained using (2).

$$\Delta IL = 0.4 \times Io \times \frac{VDC}{VINpeak} \quad (1)$$

Where ΔIL represents the estimated inductor ripple current, *VINpeak* represents input voltage, *Vo* denotes expected output voltage, *fs* stands for minimal switching frequency, and *ΔIL* represents estimated inductor ripple current.

$$\mathrm{L} = \frac{VINpeak \times (Vo - VINpeak)}{\Delta IL \times fs \times Vo} \quad (2)$$

4. RESULTS AND DISCUSSION

4.1. Case I

The DSPic33FJ64MC802 controller is employed for the development of the suggested SPWM-based converted using CSPWM technique for rectification and inversion. The simulations are carried out using C language. The 380 V is the boosted DC voltage used, the value of the DC link capacitor is 440 µF, the line RMS voltage is 160 V, the load resistance is variable (90–225 Ω), the input inductor value is 1 mH, and the switching frequency is 20 KHz.

4.1.1. Experiment results to indicate PF in rectification using CSPWM

Simulation results for rectifying mode for different loads are visualized in Figure 3. Figure 3(a) illustrates the line current followed by the line voltage waveform that indicates the 0.987 PF is approximately unity at complete load condition. At 80% load, some disturbances appear in the line current but are negligible. The observed PF of the rectifier is 0.979, given in Figure 3(b). When the load of the rectifier becomes 20% of the entire load, the PF becomes 0.972, as shown in Figure 3(c). Channel 1 and channel 2 are set at 50 V/Div, whereas channel 3 is at 2 Amp/Div.

4.1.2. Experiment results to indicate voltage regulation in rectification using CSPWM

Figure 4 displays the output voltage regulation when the DC load is regularly changed from 5% to 80%. The experiment result is shown in trace 'a' of Figure 4; it is perceived that the DC link voltage is regulated while the load varies from 80% to 5% and back to 80%. The voltage regulation of the DC link was done within a short amount of time, which was minimal when the load changed. Channels 2 and 4 are set to 50 volts per division, whereas channel three is set to 2 amps per division. The step change and DC link voltage regulation time after a load shift are depicted in trace 'b' of Figure 4. When the load varies from 5% to 80%, the time/division knob is set to 250 msec, indicating that the voltage is regulated for 40 ms period, line current enhancement, and constant voltage.

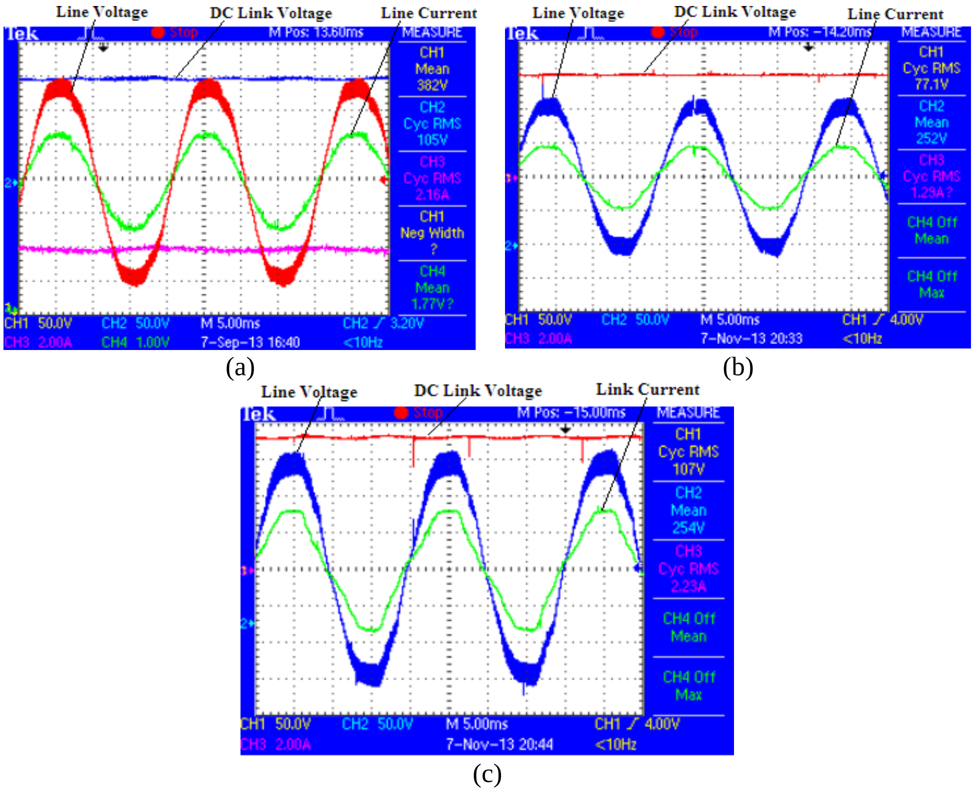


Figure 3. Experiment results: (a) PF for complete load condition, (b) PF for 80% load, and (c) PF for 20% load

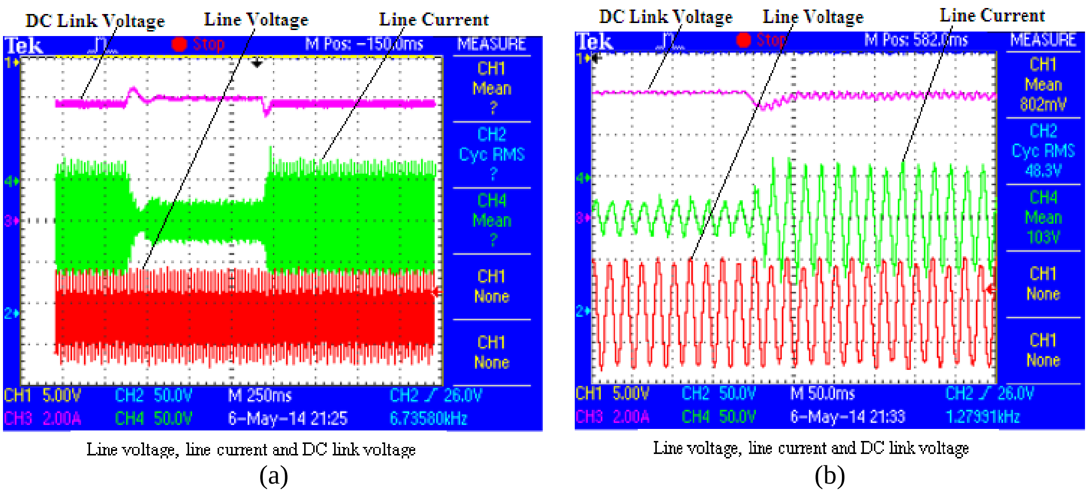


Figure 4. Experiment results of voltage regulations: (a) DC load changes periodically load varies from 80% to 5% and 5% to 80%; and (b) DC load varies from 5% to 80% to show a period of voltage regulation

4.1.3. Experiment result for bi-directional operation

The SPWM technique is used to validate the experimental result of bi-directional power flow in the inversion operation. Figure 5 shows the inversion operation using the same converter used for the rectification operation. Figure 5(a) illustrates the inverted voltage and currents, where voltage and current are 180° out of phase. Trace 1 and 2 of Figure 5(b) show the inverted output for different loads, but by changing the switch position, the inverted current and voltage are in phase. Figure 5(c) depicts the line's current harmonic pattern. All lesser-order harmonics and 3rd harmonics are eliminated, while the 5th and 7th harmonics are minimized to a minor degree.

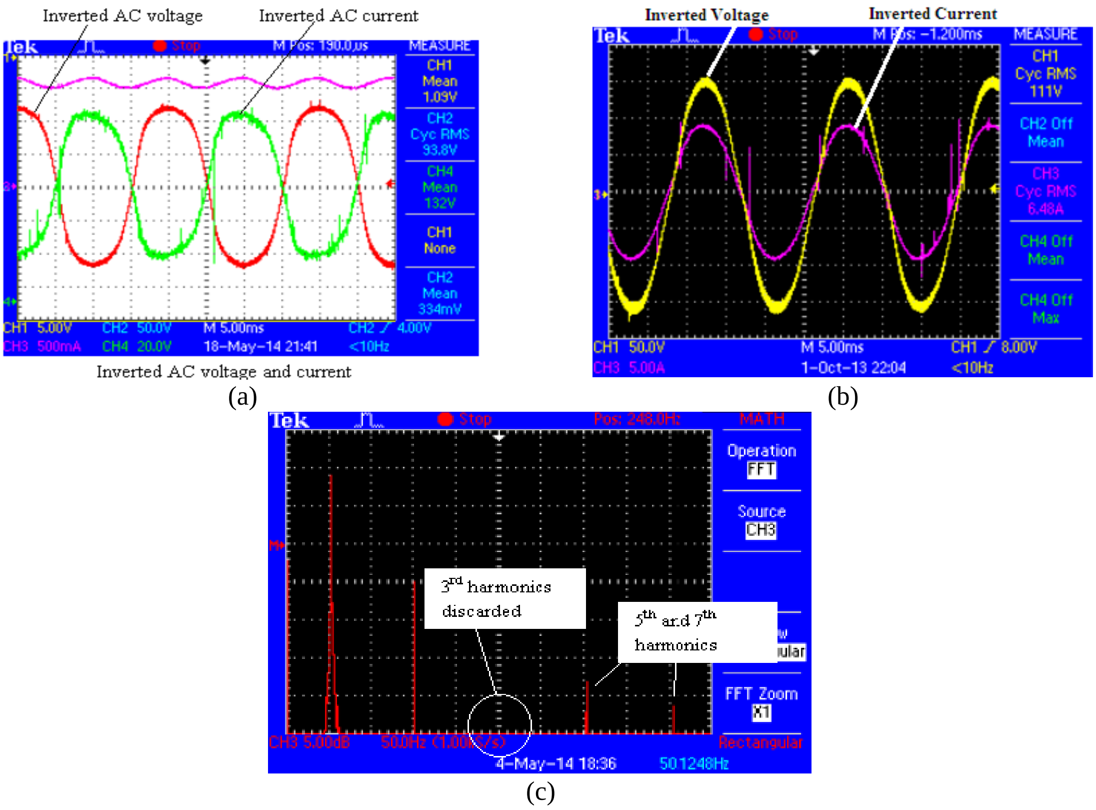


Figure 5. Experiment results of the inverter: (a) inverted voltage and current with 180° out of phase, (b) in phase, inverted voltage and current for 1 kW and 500 W resp., and (c) discarded 3rd harmonics and 5th and 7th harmonics reduction in line current

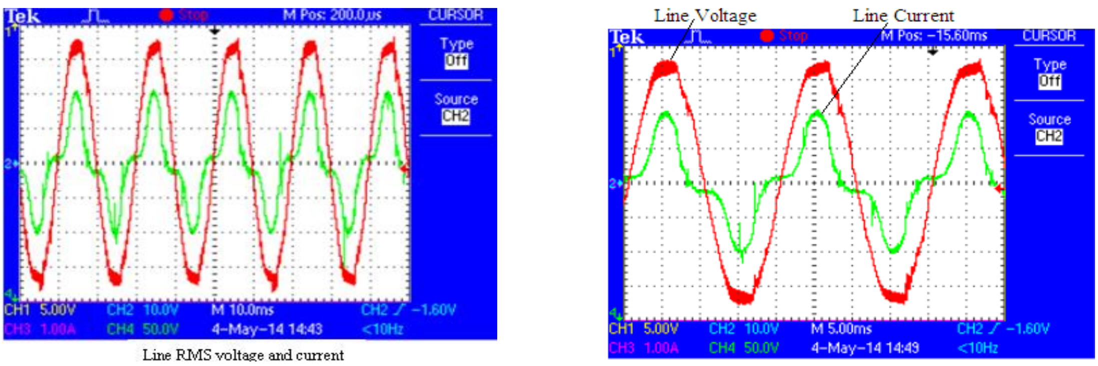
4.2. Case II

4.2.1. Experiment results to indicate PF in rectification using CSPWM

The waveforms of the experiment results for the rectifying mode for various loads are presented in Figure 6. The line current and voltage waveform in Figure 6(a) indicate a 0.80 PF at full load. These results are identical to those of the simulated waveform. Channel I is set at 50 V/Div while channel three is adjusted at 1 Amp/Div. At 80% load, more disturbances have appeared i the current. The observed PF of the rectifiers is 0.789 shown in Figure 6(b).

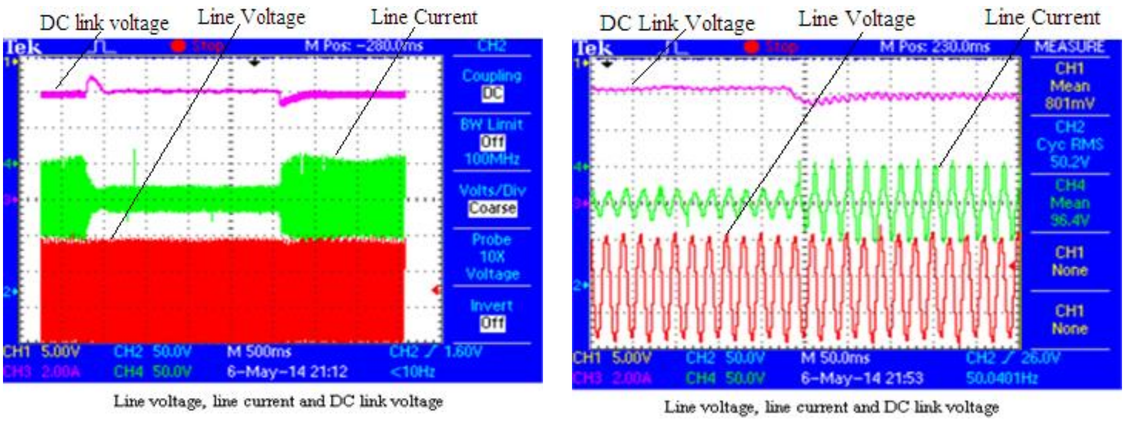
4.2.2. Experiment results to show bi-directional operation

The Case II experimental results show bi-directional working, which is the same as the results of Case I. In both cases, the same technique, SPWM, is applied to the inversion process. It shows the bi-directional working of the converter. Figure 7 shows experiment results of voltage regulations: Figure 7(a) DC load changes periodically load varies from 80% to 5% and 5% to 80%; and Figure 7(b) DC load varies from 5% to 80% to show a period of voltage regulation. The harmonic pattern of the line current is shown in Figure 8. It is observed that 3rd, 5th, and 7th harmonics exist that boost THD. Figure 9 shows the experimental laboratory setup. It includes a DSPic33FJ64MC802 digital controller, IGBT drivers, capacitor, inductor, IGBT switches, and precision rectifier.



(a) (b)

Figure 6. Experiment results: (a) PF for complete load condition and (b) PF for 80% load



(a) (b)

Figure 7. Experiment results of voltage regulations: (a) DC load changes periodically load varies from 80% to 5% and 5% to 80% and (b) DC load varies from 5% to 80% to show a period of voltage regulation

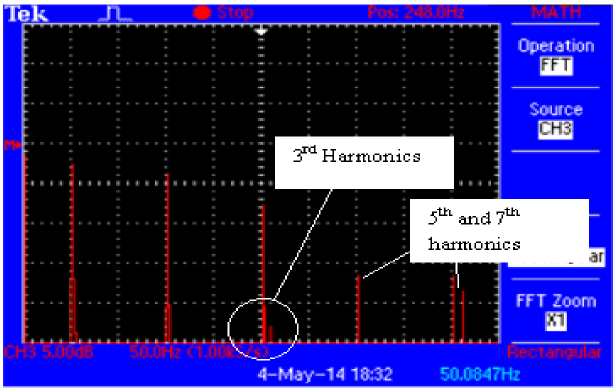


Figure 8. Third, fifth-, and seventh-line current harmonics pattern

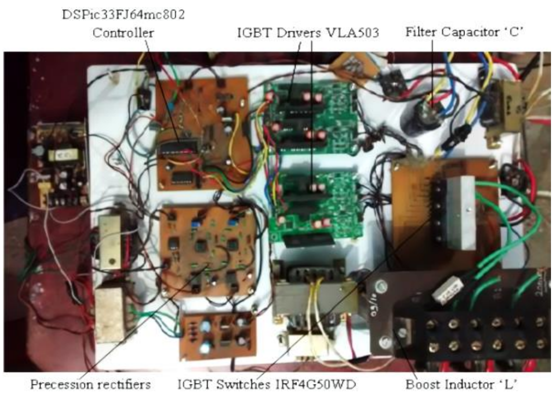


Figure 9. Laboratory model experimental set-up

5. CONCLUSION

This paper used two cases to present bi-directional CSPWM and SPWM converter with improved PF and harmonic reduction techniques. It is shown that the scheme using Case I exhibits remarkable results in parameters like PF, voltage regulations, current harmonics, and THDs compared to the scheme with Case II. The result shows total load efficiency and PF of 95.2% and 97.8%, respectively. The Case I and Case II, the total load efficiency is 75.4%, and the PF is 80.3%. The voltage regulation period in the first case is 40 msec only, and 100 msec for the second case. The line current harmonics pattern yields a better result for Case I; the 3rd harmonics are entirely suppressed, while the 5th and 7th harmonics are suppressed to an insignificant level. In Case II, the harmonics pattern of line current contains 3rd, 5th and 7th harmonics that show poor system performance. The converter system using Case I seems to have more advantages than one using Case II.

REFERENCES

[1] S. Y. Hui, H. S.-H. Chung, and S.-C. Yip, "A bidirectional AC-DC power converter with power factor correction," *IEEE Transactions on Power Electronics*, vol. 15, no. 5, pp. 942–948, Sep. 2000, doi: 10.1109/63.867684.

[2] S. A. Q. Mohammed and J.-W. Jung, "A state-of-the-art review on soft-switching techniques for DC–DC, DC–AC, AC–DC, and AC–AC power converters," *IEEE Transactions on Industrial Informatics*, vol. 17, no. 10, pp. 6569–6582, Oct. 2021, doi: 10.1109/TII.2021.3058218.

[3] S. S. Kadlag, M. P. Thakre, R. Mapari, R. Shriwastava, P. C. Tapre, and D. P. Kadam, "A novel pulse charger with intelligent battery management system for fast charging of electric vehicle," *Bulletin of Electrical Engineering and Informatics*, vol. 12, no. 3, pp. 1388–1396, Jun. 2023, doi: 10.11591/eei.v12i3.4890.

[4] Y. M. Alsmadi, V. Utkin, M. Haj-Ahmed, L. Xu, and A. Y. Abdelaziz, "Sliding-mode control of power converters: AC/DC converters & DC/AC inverters," *International Journal of Control*, vol. 91, no. 11, pp. 2573–2587, Nov. 2018, doi: 10.1080/00207179.2017.1390263.

[5] S. Li *et al.*, "The bidirectional AC/DC power converter with capability of suppressing the harmonic current in hybrid micro grid," in *2018 Asian Conference on Energy, Power and Transportation Electrification (ACEPT)*, IEEE, Oct. 2018, pp. 1–6, doi: 10.1109/ACEPT.2018.8610667.

[6] A. R. Prasad, P. D. Ziogas, and S. Manias, "A novel passive waveshaping method for single-phase diode rectifiers," *IEEE Transactions on Industrial Electronics*, vol. 37, no. 6, pp. 521–530, 1990, doi: 10.1109/41.103457.

[7] A. Franco de Souza, E. R. Ribeiro, E. M. Vicente, and F. L. Tofoli, "Experimental evaluation of active power factor correction techniques in a single-phase AC-DC boost converter," *International Journal of Circuit Theory and Applications*, vol. 47, no. 9, pp. 1529–1553, Sep. 2019, doi: 10.1002/cta.2664.

[8] R. Oruganti and R. Srinivasan, "Single phase power factor correction — A review," *Sadhana*, vol. 22, no. 6, pp. 753–780, Dec. 1997, doi: 10.1007/BF02745844.

[9] F. C. Schwarz, "A time-domain analysis of the power factor for a rectifier filter system with over- and subcritical inductance," *IEEE Transactions on Industrial Electronics and Control Instrumentation*, vol. IECI-20, no. 2, pp. 61–68, May 1973, doi: 10.1109/TIECI.1973.5408886.

[10] R. Redl and L. Balogh, "Power-factor correction in bridge and voltage-doubler rectifier circuits with inductors and capacitors," in *Proceedings of 1995 IEEE Applied Power Electronics Conference and Exposition - APEC'95*, vol. 1, IEEE, 1995, pp. 466–472, doi: 10.1109/APEC.1995.468989.

[11] J. W. Kolar, U. Drofenik, and F. C. Zach, "VIENNA rectifier II-a novel single-stage high-frequency isolated three-phase PWM rectifier system," *IEEE Transactions on Industrial Electronics*, vol. 46, no. 4, pp. 674–691, 1999, doi: 10.1109/41.778214.

[12] A. D. Pathak, R. E. Locher, and H. S. Mazumdar, "3-phase power factor correction, using Vienna rectifier approach and modular construction for improved overall performance, efficiency, and reliability," *Power electronics conf. in Long Bench*, pp. 1–13, 2003.

[13] H. Chen, N. David, and D. C. Aliprantis, "Analysis of permanent-magnet synchronous generator with Vienna rectifier for wind energy conversion system," *IEEE Transactions on Sustainable Energy*, vol. 4, no. 1, pp. 154–163, Jan. 2013, doi: 10.1109/TSTE.2012.2208660.

[14] M. Khazraei, H. Sepahvand, M. Ferdowsi, and K. A. Corzine, "Hysteresis-based control of a single-phase multilevel flying capacitor active rectifier," *IEEE Transactions on Power Electronics*, vol. 28, no. 1, pp. 154–164, Jan. 2013, doi: 10.1109/TPEL.2012.2197222.

[15] T. Tanaka, T. Sekiya, H. Tanaka, M. Okamoto, and E. Hiraki, "Smart charger for electric vehicles with power-quality compensator on single-phase three-wire distribution feeders," *IEEE Transactions on Industry Applications*, vol. 49, no. 6, pp. 2628–2635, Nov. 2013, doi: 10.1109/TIA.2013.2262915.

[16] A. Munsi, P. Pal, and S. Chowdhuri, "An efficient G2V and V2G converter systems for EV application," in *2020 IEEE Calcutta Conference (CALCON)*, IEEE, Feb. 2020, pp. 194–199, doi: 10.1109/CALCON49167.2020.9106481.

[17] T. Kohama, S. Hasebe, and S. Tsuji, "Simple bidirectional power line communication with switching converters in DC power distribution network," in *2019 IEEE International Conference on Industrial Technology (ICIT)*, IEEE, Feb. 2019, pp. 539–543, doi: 10.1109/ICIT.2019.8755053.

[18] S. Navinchandran and M. Sujith, "Bidirectional on-board single phase electric vehicle charger with high gain boost converter for V2G application," in *2020 Fourth International Conference on Inventive Systems and Control (ICISC)*, IEEE, Jan. 2020, pp. 363–368, doi: 10.1109/ICISC47916.2020.9171133.

[19] O. Rakesh and K. Anuradha, "Analysis of bidirectional DC-DC converter with wide voltage gain for charging of electric vehicle," in *2021 7th International Conference on Electrical Energy Systems (ICEES)*, IEEE, Feb. 2021, pp. 135–140, doi: 10.1109/ICEES51510.2021.9383709.

[20] X. Zhang, L. Li, and C. Wan, "Small-signal modeling of CLLC bidirectional resonant converters," in *2020 15th IEEE Conference on Industrial Electronics and Applications (ICIEA)*, IEEE, Nov. 2020, pp. 794–798, doi: 10.1109/ICIEA48937.2020.9248334.

[21] S. S. Kadlag, P. Tapre, R. Mapari, M. Thakre, D. Kadam, and D. Dahigaonkar, "Pulse charging based intelligent battery management system for electric vehicle," *Bulletin of Electrical Engineering and Informatics*, vol. 12, no. 4, pp. 1947–1959, Aug. 2023, doi: 10.11591/eei.v12i4.4564.

[22] D. V. Ghodke, K. Chatterjee, and B. G. Fernandes, "Modified one-cycle controlled bidirectional high-power-factor AC-to-DC converter," *IEEE Transactions on Industrial Electronics*, vol. 55, no. 6, pp. 2459–2472, Jun. 2008, doi: 10.1109/TIE.2008.921671.

[23] H.-H. Lee, B. Sergey, V.-T. Phan, and T.-W. Chun, "A novel control strategy for three-phase rectifier with high power factor," in *IECON 2006 - 32nd Annual Conference on IEEE Industrial Electronics*, IEEE, Nov. 2006, pp. 2255–2261, doi: 10.1109/IECON.2006.347884.

[24] Y. Zhang, E. K. P. Chong, J. Hannig, and D. Estep, "Approximating extremely large networks via continuum limits," *IEEE Access*, vol. 1, pp. 577–595, 2013, doi: 10.1109/ACCESS.2013.2281668.

[25] S. Ikeda, K. Kajiwara, K. Tsuji, and F. Kurokawa, "Efficiency improvement of isolated bidirectional boost full bridge DC-DC converter," in *2018 7th International Conference on Renewable Energy Research and Applications (ICRERA)*, IEEE, Oct. 2018, pp. 673–676, doi: 10.1109/ICRERA.2018.8566997.
[26] K. Shigeuchi, J. Xu, N. Shimosato, and Y. Sato, "A modulation method to realize sinusoidal line current for bidirectional isolated three-phase AC/DC dual-active-bridge converter based on matrix converter," *IEEE Transactions on Power Electronics*, vol. 36, no. 5, pp. 6015–6029, May 2021, doi: 10.1109/TPEL.2020.3026977.
[27] R. G. Mapari, D. G. Wakde, R. G. Tambe, A. B. Kanase, and S. Patil, "Modeling and simulation of the single-phase unity power factor active rectifier for minimizing the input current harmonic distortions," *Applied Mechanics and Materials*, vol. 267, pp. 91–94, Dec. 2012, doi: 10.4028/www.scientific.net/AMM.267.91.
[28] N. Vazquez, H. Rodriguez, C. Hernandez, E. Rodriguez, and J. Arau, "Three-phase rectifier with active current injection and high efficiency," *IEEE Transactions on Industrial Electronics*, vol. 56, no. 1, pp. 110–119, Jan. 2009, doi: 10.1109/TIE.2008.926770.
[29] M. S. Arjun, N. Mohan, K. R. Sathish, A. Patil, and G. Thanmayi, "Impact of electric vehicle charging station on power quality," *International Journal of Applied Power Engineering (IJAPE)*, vol. 13, no. 1, pp. 186–193, Mar. 2024, doi: 10.11591/ijape.v13.i1.pp186-193.
[30] R. Shriwastava, S. S. Kadlag, R. S. Pawase, R. Mapari, and D. P. Kadam, "Design, simulation and implementation of FOC-SVM DCMLI driven PMSM drive," *International Journal of Electric and Hybrid Vehicles*, vol. 15, no. 4, pp. 319–334, 2023, doi: 10.1504/IJEHV.2023.136764.

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